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PEMBREY REPORT No. 181-4.

'CRASH COOLING'.

TREATMENT OF T.N.T. EFFLUENTS

25 Mar 1955

PICATINNY ARSENAL
TECHNICAL INFORMATION SECTION

BY
W. H. MORRIS.

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DECISION SHEET
to be attached to

PEMBREY REPORT No. 181/4

Title: Crash Cooling. Treatment of T.N.T. Effluents. - Pilot plant Work leading to the Design of a Full Scale "Crash Cooling" Unit incorporating Continuous Recovery and Return of Recovered T.N.T.

Authors: W.H. Morris

Submitted by: W.H. Morris

Decision: Recommendation approved.

4/7/55

K.12246

W.B. Littler
D.O.F/X

C O N F I D E N T I A L

PEMBREY REPORT NO. P.181-4

"CRASH COOLING" TREATMENT OF T.N.T. EFFLUENTS

Pilot Plant Work leading to the Design of a Full Scale "Crash Cooling" Unit incorporating Continuous Recovery and Return of Recovered T.N.T.

Author : W.H. Morris

Submitted by : W.H. Morris

Approved by : C.F. Mitchell
R. Edgeworth-Johnstone

Date : 25.3.55.

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The author gratefully acknowledges the assistance of Mr. W. Underwood, Chemist III/Development, who assisted in the pilot plant operation, and in the calculations for Designs A and B.

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CONTENTS

DEVELOPMENT PROGRAMME NO. P.181

1. Title

Treatment of T.N.T. Washing and Sulphiting Effluents.

2. Reasons

(a) There is some evidence that organic acids are being recirculated with the T.N.T. recovered from the effluent labyrinths, causing a build up of organic acids in the system.

(b) Increasing attention is being focused on factory effluents throughout the country, and it is felt that more information on washing and sulphiting effluents is desirable.

3. Objects

(a) To improve the overall efficiency and economics of the recovery process.

(b) To determine a method of treatment of recovered material suitable for inclusion with a packed tower T.N.T. washing process.

(c) To develop methods of treating effluents for the recovery of T.N.T. and the reduction of organic material going to water.

4. Procedure

(a) To establish material balances at the washing and sulphiting houses, including the effluent labyrinths and ponds, to clarify the problem.

(Subsequent investigation will depend somewhat upon the results obtained in (a) but will probably include the following) :-

(b) Investigation on the laboratory scale, to determine a suitable method for treatment of the recovered material, possibly by neutralisation of the organic acid or separation by suitable solvents.

(c) Investigation into the possibility of neutralising the organic acid using sodium carbonate, sodium bicarbonate, sodium sulphite or some other suitable neutralising agent, as part of the normal washing process.

(d) Investigation of the possibility of neutralising the acid effluent with sulphite liquor effluent.

Submitted by : W.H. MORRIS

Approved by : H.J. DRINKALL
R.E. JOHNSTONE

Date : 19.2.54.

SUMMARY

A pilot plant for the treatment of the effluents from the T.N.T. purification house has been designed, erected and operated to obtain data for the design of full scale units. The treatment involves continuous "Crash Cooling" of the hot effluent in a heat exchanger of the stirred vessel type, using a gate paddle stirrer with small clearance between the paddle and the coil. Coils fabricated from lead, stainless steel and mild steel were tried out.

The following information was included in the data obtained :-

(a) Icing of the coils was moderate at effluent outlet temperatures of 30°C., but severe at 40°C. and very severe at 60°C.

(b) The scrubbing action resulting from the gate paddle with small clearance ($\frac{3}{4}$") between paddle and coil was beneficial in helping to reduce the effect of "icing", and gave good results for the Overall Coefficient of Heat Transfer.

(c) With minor differences, the icing effects using coils fabricated from lead, stainless steel and mild steel were similar. In each case the "icing" which was moderate at 30°C. increased rapidly with increased effluent exit temperature.

(d) "De-icing" of the coils could be carried out in a few minutes by passing steam through the coils - without shutting down the unit.

(e) Similar results have been obtained for both the "Acid" and Sulphite Effluents.

Separation

A new form of continuous solid/liquid separator has been developed which operates well for both types of effluent, and releases the recovered material as a slurry in a continuous flow suitable for mechanical return to the purification plant.

The circular rotation of the liquid in the separator - promoted by the entry of the effluent at a tangent - is beneficial to separation.

Full Scale Units

Two alternative full scale designs have been worked out, one in the form of four small coolers operated in parallel, and the other in the form of a single large cooler designed to make use of a redundant P.24 Washer. Each is designed for a throughput of up to 1,200 g.p.h. of effluent at 87°C., with a final effluent temperature of 30°C. Continuous separation and mechanical return of the recovered material to the Purification House is provided in each case.

RECOMMENDATIONS

1. That although the installation of a continuous "Crash Cooling" Unit, embodying the principles of design indicated in this report, would be practicable and advantageous, action on the report should be delayed pending the outcome of work on the Cold Sulphiting Programme No. P.186.

REFERENCES

Ref. No.

1 R.O.F.34, Report No. P.181-1, W.H. Morris, 18.3.54. "An Investigation into the Acid Effluent Recovery System at the T.N.T. Washing and Sulphiting House".

2 R.O.F.34, Report No. P.181-2, W.H. Morris, 15.9.54. "An Investigation into the Material Balances for the Sulphiting and Post Sulphite Washing Operations and Effluent Recovery System at the T.N.T. Washing and Sulphiting House".

3 R.O.F.34, Report No. P.171B, W.H. Morris, 6.7.54. "The Tower Washing of Crude T.N.T.: Full Scale Trials".

4 R.O.F.34, Report No. P.181-3, W.H. Morris, 3.11.54. "A Combination of Hot Water Washing in a Packed Tower and Sodium Carbonate Solution Washing in a Stirred Vessel - with Recovery of Sulphuric Acid".

5 McAdams - Heat Transmission.

6 Perry (Editor) - Chemical Engineers Handbook, 3rd Ed.

INTRODUCTION

The investigation reported here is a continuation of Programme P.181, "Treatment of T.N.T. Washing and Sulphiting Effluents".

The investigation into the material balances for the Washing and Sulphiting Processes reported in P.181-1 (1) and P.181-2 (2), showed that out of a total loss of 6.5% for the overall efficiency of the purification processes, 3.8% is due to the removal of unsymmetrical T.N.T., 2.4% is due to the breakdown of ~~ T.N.T. during the sulphiting process, and only 0.3% is due to the loss of recoverable T.N.T. in the effluents. It was also shown (2, p.23) however, that the cost of recovery was high at £55 per s. ton of T.N.T. recovered, and that this was due to the large labour force required for draining the ponds, digging out the recovered material from ponds and labyrinths, and transportation back to the plant. For this reason, further development work was recommended (2) to reduce this cost, by (a) reducing the volume of recovery i.e. of effluent, and (b) by the development of a crash cooling plant with mechanical recovery and return of the recovered material.

Some reduction in the volume of recovery has already been effected by the introduction of packed tower washing (3) and a further very big reduction has been suggested (4) by the use of a combination of hot water washing in a packed tower and sodium carbonate washing in a stirred vessel. This report deals with part (b) of the recommendation i.e. rapid cooling of the effluents with separation and mechanical return of the precipitated T.N.T.

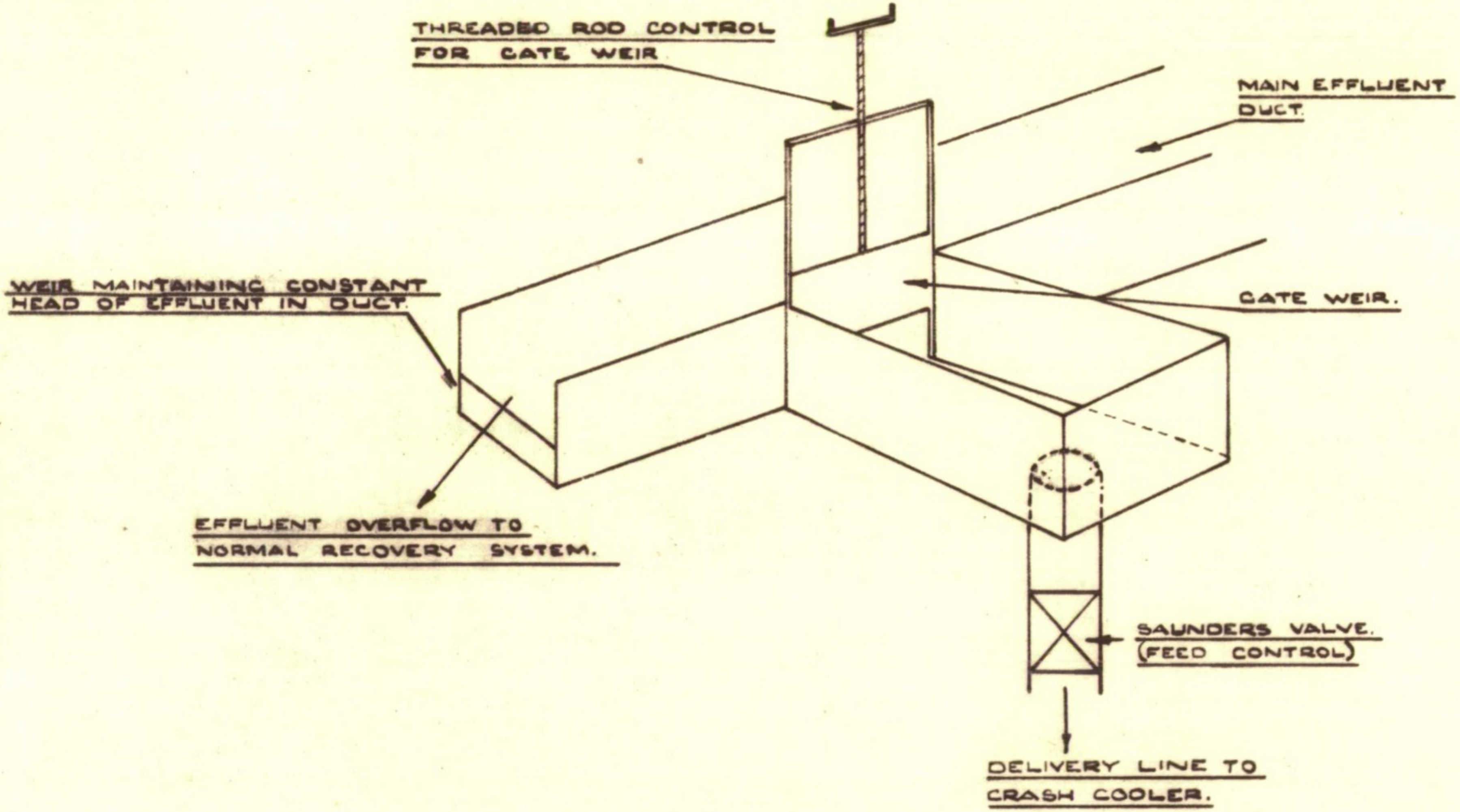
In addition to any possible economic gain, the successful outcome of this development would eliminate the manual handling of recovered T.N.T. with a consequent improvement in man/hour - production, reduction in health hazard and improved cleanliness of the Purification Buildings and surrounds.

Theoretical Considerations

The conception of cooling a solution in a heat transfer unit, for removal of most of the dissolved material from solution, has the potential disadvantage that the material removed from solution will settle out on the cooling surface. The resulting "icing" of the cooling surface will rapidly reduce the efficiency of the unit to a level below the requirement for economical operation.

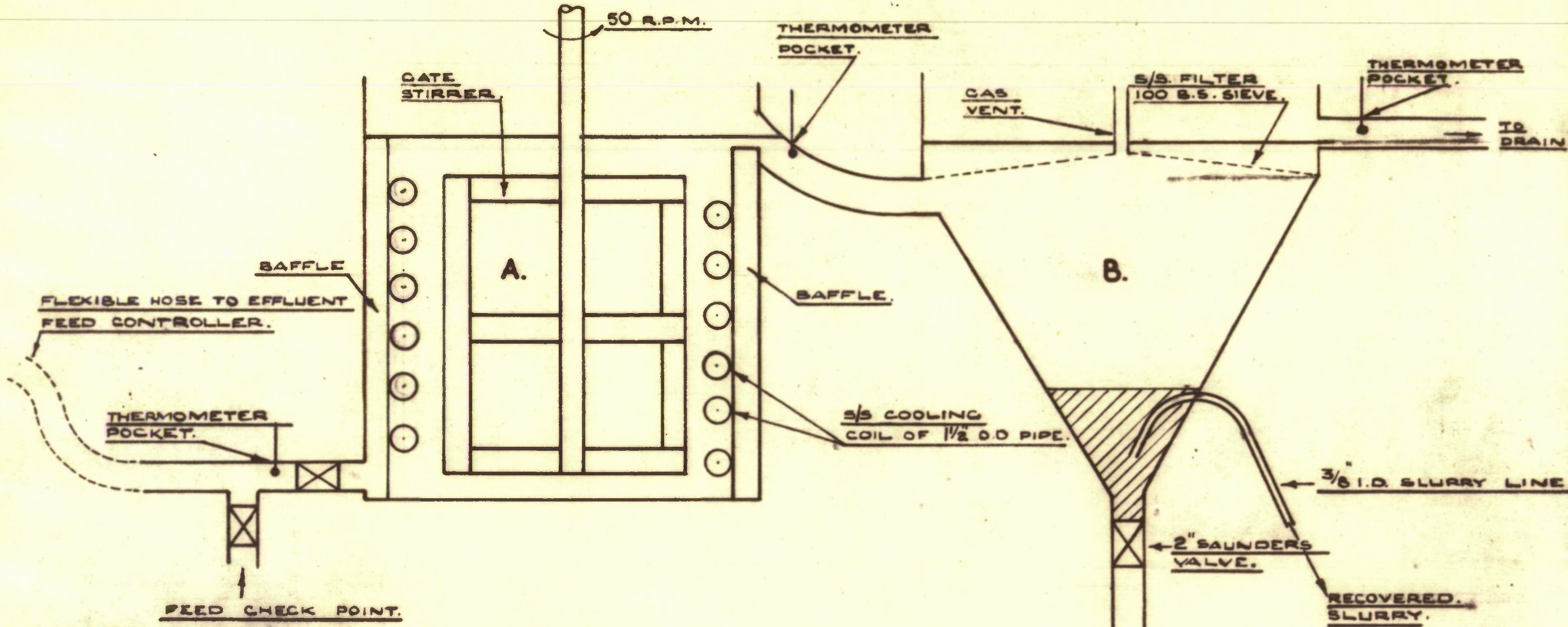
It should be possible to overcome this difficulty by designing the cooling unit so that the cooling is brought about instantaneously - crash cooling - by mixture with a comparatively large bulk of the previously cooled liquid, rather than by heat transfer at the cooling surface of the transfer unit. A cooler meeting these requirements would be one containing a bulk of liquid maintained at a sufficiently low temperature by means of cooling surfaces and agitated to maintain a uniform temperature throughout the bulk of the liquid.

The pilot plant Cooler for T.N.T. effluents was designed to meet these requirements, and because of the rapid cooling involved has been called a "Crash Cooler".



EFFLUENT FEED CONTROLLER FOR CRASH COOLING.
PILOT PLANT.

C.P. 311.



DIMENSIONS.

A. CRASH COOLING VESSEL.
DIA. = 2' × HT. = 2'-8"
LIQUID HIGHT = 2'-4"
EFF. INLET & OUTLET LINES = 3" I/D
GATE STIRRER
DIA. = VARIABLE, HT. = 1'-6"
CLEARANCE BETWEEN PADDLE & COIL
= 1½" (S.S. COIL)
& 3/4" (LEAD & M/S COIL)

B. SEPARATOR.
DIA. AT MESH = 2'-0"
HT. (MESH TO APEX OF CONE) = 2'-0"

CRASH COOLING - T.N.T. EFFLUENTS

PILOT PLANT

C.P. 310.

C.P. 310.

THE PILOT PLANT

A "crash cooling" pilot plant was designed, and erected alongside the effluent labyrinths within the traverse of the Purification House, P.24. It was designed for the purpose of obtaining the following information :-

(a) The feasibility of the method, including the separation of the recovered material, and its return to the purification plant.

(b) Data necessary for the design of a full scale "crash cooling" unit.

The final arrangement is shown diagrammatically in drawing C.P. 310. The unit was constructed entirely from spare and scrap units, and materials found on site. Thus separator B was a slightly modified stainless steel (F.D.P. quality) airlift separator cyclone of standard size and design - Pembrey Drawing E.D.O. 382/M/13 "Cyclone Separator for Air Lifts" - adapted for the purpose. The crash cooling tank, also of F.D.P. quality stainless steel, was provided with a cooling coil (various) and 4 equidistant baffles. The agitation was effected by means of a gate stirrer - Drawing C.P. 310 - revolving at 123 r.p.m. This form of agitation was chosen because with a small clearance between the coil and the outer edge of the gate paddle, the maximum degree of agitation could be localised in the region of the coil, without the need for high speed stirring. It was hoped that the scrubbing effect produced near the surface of the coil would reduce or prevent any "icing" of the coil.

The hot effluent entered the crash cooling tank A via a 3" i.d. stainless steel line at the bottom of the tank. The cooled effluent containing suspended particles of nitrobody overflowed via a 3" i.d. stainless line and entering the separator B at a tangent producing a circular movement in the liquid which was designed to facilitate separation. The separated solid particles migrated to the base of the separator and were withdrawn in the form of a slurry via the $\frac{3}{8}$" i.d. slurry line. The slurry could also be withdrawn via the 2" Saunders Valve at the base of the conical separator.

The liquid effluent passed upwards through a stainless steel 100 B.S. Sieve which filtered out any remaining nitrobody particles prior to the effluent overflowing to drain.

Thermometer pockets were provided in the effluent entry and exit lines to the crash cooling tank, and facilities were provided for measuring the cooling water and effluent flows by volume/time checks. The effluent flow to the cooler was controlled by means of the arrangement illustrated in Sketch C.P. 311. The weir ensured a constant head of effluent to the controlling Saunders valve. The gate weir provided an alternative method to the valve for shutting off the effluent feed to the pilot plant, and was used for all except temporary shut-downs. Its use eliminated blockage of the line with entrained T.N.T. during shut-down periods.

EXPERIMENTAL METHOD

Experimental runs were carried out on the pilot plant with both the "Acid" and the "Sulphite" effluents.

1. Crash Cooler

The effect of "icing", for various effluent exit temperatures (30°C., 40°C. and 60°C.), was determined by the variation in the overall co-efficient of heat transfer over the duration of each run. The investigation was duplicated for a lead, a stainless steel and a mild steel coil.

The procedure for each run was as follows :-

(a) The cooling water to the coil was set to the required level.

(b) The cooler was filled with cold water and the stirrer mechanism started up.

(c) The effluent feed was commenced at a low rate and was gradually increased to give the required effluent exit temperature.

(d) When conditions were steady - approximately $1\frac{1}{2}$ hours after start up - the water and the effluent feeds were measured by time/volume checks, and the inlet and outlet temperatures of both feeds recorded. The overall coefficient of Heat Transfer (U) calculated from these figures has been recorded as the starting (0 hours) value.

(e) Several measurements of feeds and temperatures for heat transfer calculations were made at intervals during each run.

(f) For the duration of each run the effluent feed was adjusted to maintain the effluent exit temperature at a constant value, i.e. the feed was gradually reduced as "icing" of the coil developed.

2. Separator

During the experimental runs detailed above, attention was also paid to the efficiency of the separation system and modifications were made to the design as required. These are detailed later (Discussion of Results Section 2).

The efficiency of the separation for both types of effluent was also investigated. Samples of the separated effluent were taken and analysed for the presence of entrained nitrobody by the method previously described in report P.181-1 (1).

During the course of this work the main considerations were :-

(a) Good separation

(b) Continuous separation of the separated nitrobody in a form suitable for its mechanical return to the purification plant.

HEAT TRANSFER RESULTS

Conditions of Run Including Outer Cooling Area of Coil = A	Run No.	Duration of Run Hrs.	Effluent Flow lbs./Hr.	Effluent Temperature °F. In	Effluent Temperature °F. Out	Approx. quantity of Heat B.T.U./Hr.	Cooling Water Flow lbs./Hr.	Cooling Water Temperature °F. In	Cooling Water Temperature °F. Out	Quantity of Heat B.T.U./Hr.(q)	Log. Mean Temp. °F. Δt_m	Overall Coefficient of heat transfer B.T.U./hr./sq.ft./°F.(U)	Remarks
						ACID EFFLUENT							
LEAD COIL (O.D. 2")	1	0	810	179.6	86.9	75,087	6,000	59.9	74.3	86,400	18.9	231	
A = 19.8 sq.ft.		$1\frac{1}{4}$	810	179.6	87.8	74,358	6,000	59.9	77.5	75,600	17.6	217	
		$2\frac{1}{4}$	810	179.6	87.8	74,358	6,000	59.9	77.5	75,600	17.6	217	
Effluent Exit Temp.	2	6	720	165	87.0	56,170	6,000	62.2	71.6	56,400	19.8	144	Coil looked cleaner after
≃ 86°F. (30°C.)		12	820	169	90.8	64,370	6,000	67.5	77.5	60,000	17.85	170	12 hours
	3	0	660	176.9	86.9	61,200	5,640	63.5	74.8	67,730	17.1	188	
		24	660	181	82.8	57,950	5,710	63.0	73.0	57,100	24.5	118	
		30	660	183.2	93.2	59,400	5,640	62.6	72.0	53,000	25.6	105	
LEAD COIL - A = 19.8 sq.ft.	4	0	1,500	183.2	107.6	117,900	6,000	61.2	80.6	110,400	35.8	156	
Effluent Exit Temp.		4	1,500	183.2	113.9	103,950	6,000	61.2	80.2	114,000	42.4	136	
105°F. (40°C.)		10	1,500	183.2	114.8	102,600	6,000	61.9	78.0	99,300	44.1	114	Coil badly "Iced"
LEAD COIL - A = 19.8 sq.ft.	5	0	2,600	184.1	121.1	163,800	6,000	61.7	87.8	156,600	45.0	176	
Effluent Exit Temp.		$\frac{3}{4}$	2,600	176.9	122.9	140,400	5,450	61.7	84.6	125,350	47.2	134	
≃ 140°F. (60°C.)		$2\frac{1}{4}$	2,600	178.7	131	124,020	5,450	61.7	84.2	122,625	57.4	108	Coil badly "Iced"
STAINLESS STEEL COIL	6	0	700	178.1	86.7	64,000	5,510	59.0	69.4	57,300	21.9	179	No Baffles
A = 14.6 sq.ft. (O.D. $1\frac{1}{2}$")													
Effluent Exit Temp.	7	0	770	172.4	87.8	65,390	5,510	58.6	70.7	66,670	22.6	202	With Baffles
≃ 86°F. (30°C.)		30	770	180.5	93.6	66,990	6,140	57.6	68.2	65,080	30.3	147	
STAINLESS STEEL COIL	8	0	1,820	181.5	103.8	141,500	5,540	42.6	66.5	132,500	48.0	188	
A = 14.6 sq.ft.		$1\frac{1}{4}$	1,720	179.5	103.7	109,500	5,540	42.6	63.3	115,000	50.0	152	
Effluent Exit Temp.		$3\frac{1}{4}$	1,335	180.0	102.8	103,100	5,540	42.6	60.2	99,500	50.2	136	
≃ 105°F. (40°C.)		$5\frac{1}{4}$	1,180	176.0	103.6	85,400	5,520	46.6	58.8	87,700	52.4	114	Coil badly "Iced"
STAINLESS STEEL COIL	9	0	3,700	184.0	142.0	155,000	4,800	42.3	78.1	172,000	82.3	143	
A = 14.6 sq.ft.		$1\frac{1}{2}$	1,610	183.5	140.2	69,700	4,200	42.3	56.6	67,200	90.1	51	Coil very badly "Iced"
Effluent Exit Temp.		3	1,335	183.1	139.5	59,200	5,260	42.3	53.4	62,600	90.7	47	"
≃ 140°F. (60°C.)		5	1,160	182.0	143.8	44,200	5,030	42.3	50.2	39,800	97.4	28	"

						SULPHITE EFFLUENT							
		0	1,200	177.8	91.1	104,000	5,000	50.5	69.5	95,000	30.2	215	
STAINLESS STEEL COIL		8½	975	177.1	90.5	84,500	5,580	49.2	63.0	77,000	33.9	155	
A = 14.6 sq.ft.	10	16	893	175.4	90.0	76,500	5,000	47.8	60.3	62,500	35.3	121	
		23	900	177.0	93.2	75,500	5,330	49.6	62.4	68,200	36.6	128	
Effluant Exit Temp.		30	774	165.0	86.5	60,400	5,670	50.7	60.4	55,000	36.5	123	
≏ 86°F. (30°C.)		50	846	178.0	86.3	77,300	5,240	49.7	63.5	72,700	29.0	171	Coils cleaner than for 30 hours. Patchas free from "Icing"
STAINLESS STEEL COIL		0	1,870	170.4	99.3	133,000	5,220	43.5	70.5	141,000	40.7	236	
A = 14.6 sq.ft.	11	1½	2,330	146.0	103.9	98,000	4,980	43.5	66.1	86,500	48.0	223	Abnormally low Eff. Inlet Temp.
Effluent Exit Temp.		3	1,500	175.7	104.6	106,500	5,300	43.5	61.3	94,200	51.9	124	Coil badly "Iced"
≏ 105°F. (40°C.)		5	895	174.2	101.2	66,300	5,220	43.5	56.8	69,500	50.7	84	Coil very badly "Iced"
STAINLESS STEEL COIL		0	6,550	176.0	141.0	229,000	4,410	44.1	85.4	183,000	75.8	165	
A = 14.6 aq.ft.	12	1¼	3,310	177.0	139.0	126,500	4,950	44.1	67.0	113,500	82.4	94	
Effluent Exit Temp.		2¼	2,420	179.0	140.6	92,800	4,950	44.1	61.3	85,000	87.1	66.5	Coil very badly "Icad"
≏ 140°F. (60°C.)		4	1,395	178.4	137.7	56,700	4,950	44.1	56.3	60,300	86.7	47.5	
STAINLESS STEEL COIL		0	1,820	172.5	88.7	147,500	13,900	51.8	62.2	145,000	31.6	313	Saa Note 3 below
A = 14.6 sq.ft.	13	19	1,270	175.2	90.6	107,200	12,000	51.8	56.1	99,200	36.7	185	
Effluent Exit Tamp.		27	1,420	175.2	88.9	122,500	12,560	47.8	55.7	104,000	37.3	190	Patchas of Coil free from "Icing"
≏ 86°F. (30°C.)													
Increased Conling Water Feed		34	1,040	173.0	87.8	88,500	12,000	50.5	56.3	86,400	35.2	168	
MILD STEEL COIL (O.D. 1⅝")		0	756	176.5	91.5	64,200	4,860	42.1	53.6	55,900	42.6	305	The "Icing" was much
A = 4.3 sq.ft.		2	537	175.2	85.9	48,000	4,700	42.1	51.3	47,000	38.9	259	thinner and harder
(Rusted Condition)		3	679	175.2	90.2	57,700	4,800	42.1	52.3	49,000	42.0	271	than was the case with
Effluent Exit Temp.	14	5	430	176.7	85.6	39,100	3,700	42.1	51.1	33,300	39.0	199	lead or stainleas steel
≏ 86°F. (30°C.)		8	330	176.5	84.5	30,350	4,800	41.2	48.2	33,600	39.5	200	coils
		11	453	168.2	88.3	36,500	4,500	41.7	49.1	33,300	42.5	183	
		15	386	172.2	90.3	31,600	4,[illegible]00	40.3	47.1	32,700	45.8	167	
		24	318	174.0	85.2	28,200	4,800	41.4	46.4	24,000	39.5	142	
MILD STEEL COIL (Rusted)		0	910	180.2	104.4	68,800	4,800	46.8	58.7	62,000	50.5	285	"
A = 4.3 aq.ft.	15	3	751	179.4	107.6	54,000	4,400	46.8	57.9	48,800	54.8	207	
Effluent Exit Temp.		4½	548	179.8	102.8	42,200	4,480	46.8	55.4	38,600	51.5	173	
≏ 105°F. (40°C.)		7	476	180.5	106.5	35,300	4,700	46.8	53.1	29,600	55.3	122	
MILD STEEL COIL (Rusted)		0	3,400	167.5	136.0	107,000	4,800	46.4	67.3	99,500	79.1	293	"
A = 4.3 sq.ft.	16	1½	1,900	180.0	141.0	74,000	5,260	46.4	59.6	70,500	86.8	189	
Effluent Exit Temp.		3½	970	181.0	144.8	35,100	5,160	46.4	52.2	29,900	95.4	73	
≏ 140°F. (60°C.)		5½	700	178.2	140.3	26,500	4,700	46.4	51.6	24,500	91.2	63	

NOTES : 1. "0" hours duration of run is time when equilibrium has been reachad for the required condition at the start of each run and is from 30 mins. - 2 hours after actual start up. The values of U for the start up time of "0" hours are therefore not strictly comparabla.

2. (Column 7) The quantity of heat figures have been obtained on the assumption that the specific haat of the Effluent is 1 and are therefore approximate only.

3. Equilibrium in the conditions was reached very rapidly in the case of the small mild steel coil and this can account for the better starting value for U.

DISCUSSION OF RESULTS AND OBSERVATIONS

1. CRASH COOLING

The heat transfer results are shown in tabulated form. The values for the Overall Coefficients of Heat Transfer were calculated from the formula :-

$$U = q/A/\Delta t^{m}$$

Where U = Overall Coefficient of Heat Transfer (B.T.U./Hr./Sq. ft./°F.)

q = Quantity of heat transferred (B.T.Us./Hr.)

A = Outer Cooling Area of Coil (sq. ft.)

Δt^{m} = Logarithmic Mean Temperature (°F.)

The quantity of heat 'q' used in the calculations was that obtained from the cooling water inlet and outlet temperatures rather than from the effluent temperatures - which was estimated on the assumption that the specific heat was Unity. - As may be seen from the results this estimation proved to be a close approximation.

The inlet and outlet temperatures of the effluent were taken as being identical - i.e. no temperature gradient - for calculations of the logarithmic mean temperature. Actual temperature measurements at various points within the bulk of the liquid confirmed that for all practical purposes this was actually the case, i.e. the cooler was an efficient "Crash Cooler" as defined in the Introduction.

The following deductions may be made from the results :-

(a) The values of U obtained for the coil in a reasonably clean condition - at the commencement of each run - indicate a good heat transfer efficiency. ("Perry" quotes a figure of 90 - 360 for U for a lead coil and for heat transfer from hot to cold water for a paddle stirrer at 40 r.p.m.). The good values are attributed to the small clearance between the paddle stirrer and the coil, an arrangement which would appear to be very effective for breaking the liquid film on the outer surface of the coil.

(b) There is no significant difference between the values of U for the lead, mild steel, or the stainless steel coil - for the coils in a clean condition - bearing in mind that the time taken to reach equilibrium was not constant for all runs.

(c) The rate of "icing" in the case of the lead coil would appear to be rather slower than for the stainless steel coil. The figures are, however, not strictly comparable because the clearance between paddle and coil was smaller in the case of the lead coil. Allowing for this difference, the icing rate results may be assumed to be of the same order for all coils.

(d) The rate of icing increases rapidly with increased effluent exit temperatures for all coils.

Observations made during the Investigation

The inside face of the coil, immediately opposite to the gate paddle tended to remain free from "icing", particularly in the case of the lead coil where the clearance between paddle and coil was small ($\frac{3}{4}$"), and for

operation at 30°C. A periodic build up of icing, followed by a flaking off to leave bare patches of coil, was also observed at this temperature of operation, particularly in the case of the stainless steel coil. Thus during the course of an experimental run at 30°C. the Overall Coefficient of Heat Transfer value would tend to fluctuate as the icing increased and then decreased. This phenomenon was not observable in the runs carried out at 40 and 60°C. where severe and progressive icing occurred in each case. In the case of the mild steel coil the "icing" was thinner but harder than for the other coils. A considerable amount of flaking occurred.

The results and observations appear to justify the choice of the gate paddle stirrer with small clearance between paddle and coil, in that

(a) the overall mixing was good as indicated by the uniformity of temperature throughout the bulk of the cooled liquid in the cooler,

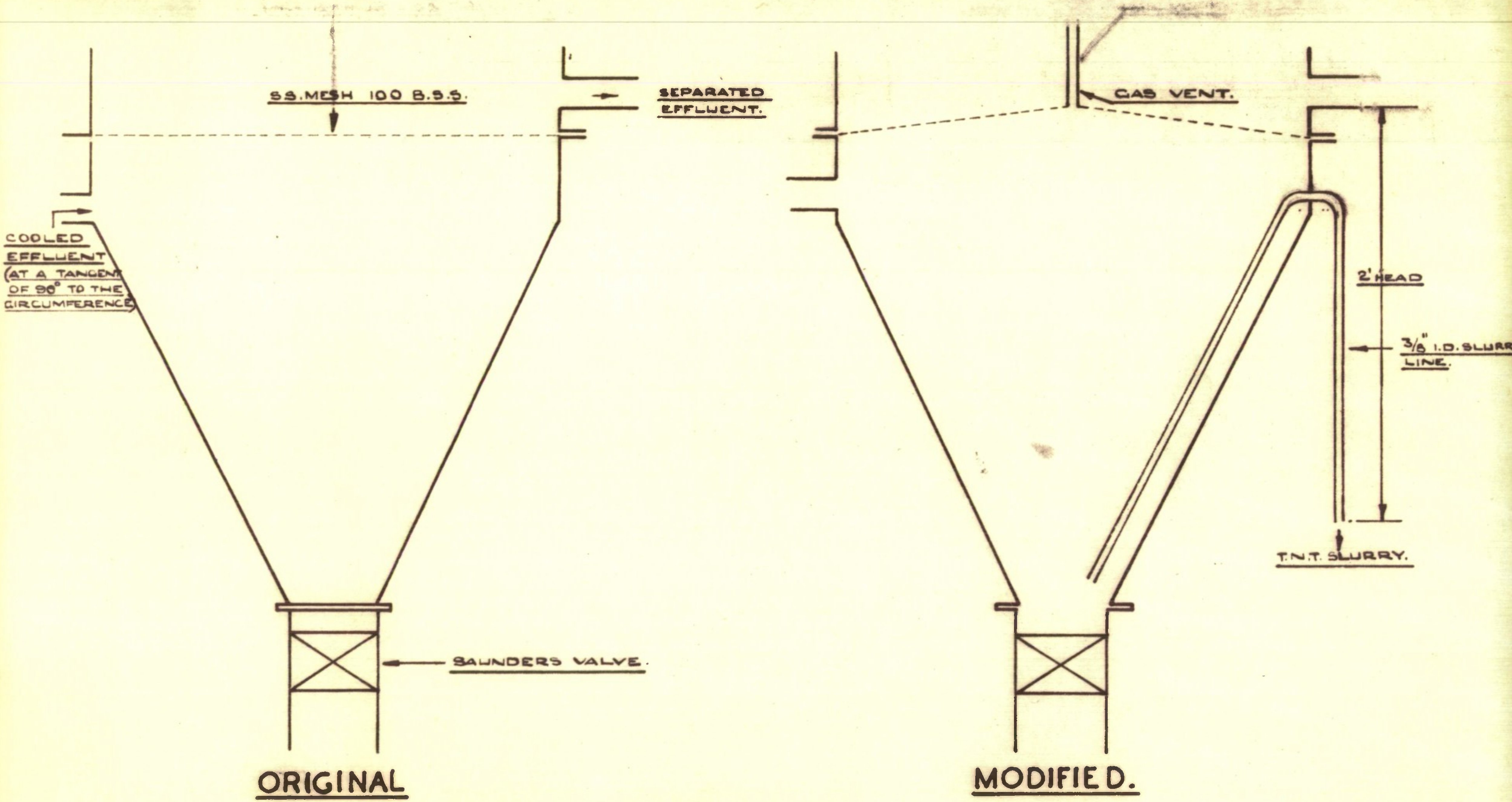
(b) the good values for U, and

(c) the scrubbing effect which tended to prevent icing on the inside of the coil.

An arrangement where both sides of the coil were scrubbed would be expected to give further advantages.

De-icing

The coils may be rapidly de-iced by passing steam in place of water through the cooling coils. De-icing of each of the pilot plant coils was effected in under three minutes by this method, without stopping the effluent flow through the cooler. The ease and speed with which this operation is carried out suggests that the effect is due to the expansion of the coil during heating.



SOLID / LIQUID SEPARATOR . PILOT PLANT FORM. C.P. 314.

C.P. 314.

2. SEPARATION AND RETURN OF RECOVERED MATERIAL

The original and final designs for the continuous solid/liquid separator are shown diagrammatically in Drawing C.P.314.

The separation was excellent from the beginning. Operating with the "Acid" effluent, the quantity of entrained solid material in the final effluent was nil throughout. Operating with the "Sulphite" effluent, some entrainment of the smaller particles was observed at the commencement of a run - with the 100 B.S. Sieve in a clean condition - but after a short period of operation the effluent cleared up, and samples analysed for entrainment again gave a nil or negligible result. At the lower effluent feeds (30°C.) the separation appeared to be quite good even when the filter was removed, and the circular rotation of the liquid, promoted by the oblique entry of the effluent, appeared to have a definitely beneficial effect.

To test this, samples of sulphite effluent were taken at the outlet of the separator with the filter removed and (a) with unimpeded circular rotation of the separator contents (b) with the rotation impeded by means of a vertical baffle situated near the point of entry.

Result

Effluent Flow g.p.h.	Entrained Nitrobody with rotation Gms./100 gms. Effluent	Entrained Nitrobody without rotation Gms./100 gms. Effluent
150	0.028%	0.042%

The original design, however, suffered from two faults :-

(a) Frequent blockage of the filter caused not by T.N.T. particles but by air, or gas liberated from the effluent. The surface tension was sufficient to prevent the gas from escaping through the mesh, even when a considerable head of liquid had been built up in the cooler.

This difficulty was overcome by the introduction of a gas vent into the centre of the filter. This vent pipe was supported by a cross piece firmly attached to the pipe and resting across the top of the separator, so that the filter was pulled upwards from the centre, thereby providing a ready escape route for the trapped gases. In this form the separator would continue to operate almost indefinitely without complete blockage of the filter.

(b) Continuous removal of the recovered solid without attention, was not possible with the original design. It had been intended to remove the separated solid, which collected at the base of the conical separator, by "cracking" the Saunders valve. This was not a success because after a short period of operation, blockage occurred which was either total or partial. In the case of a partial blockage, the blockage acted as a filter returning the solid particles and allowing the passage of liquid only.

This difficulty was eventually overcome by the insertion of $\frac{3}{8}$" i.d. stainless line, through an existing orifice in the side of the separator, as shown. This arrangement functioned excellently with a

2' head of liquid, allowing the continuous removal of T.N.T. slurry without blockage, despite the unnecessarily long length of line used. Prior to the successful outcome of this modification, lines of larger internal diameter were used. These were fitted with a valve which was "gagged back" as required. In these cases, separation of the solid particles in the slurry caused partial blockages which again filtered out the solid particles allowing the passage of liquid only. The smaller $\frac{3}{8}$" i.d. line, in conjunction with a 2' head, provided the necessary turbulent flow at the low flow requirement, and this arrangement functioned excellently for either the "Acid" or the "Sulphite" effluents.

Continuous return of the recovered material may be effected by allowing the slurry to pass into a liquid - liquid separator of normal design, provided with steam coil heating sufficient to melt and maintain the T.N.T. in a molten condition. In this way the remaining liquid may be separated off, and the molten T.N.T. airlifted continuously back to the unit. The feasibility of this method was proved by allowing the slurry to pass into a small liquid/liquid separator on the pilot plant. Continuous melting and separation was effected in this way. Alternatively the slurry itself may be pumped or steam ejected directly to the purification plant. This method has the disadvantage that some of the liquid portion containing acid or spent sulphite liquor, as the case may be, is returned to the plant, but it is to be commended for its simplicity.

Recovered material from the "Acid" effluent will contain approximately 25% of organic acid (1) and should be returned to the presulphite washing stage as is present normal practice. Recovered material from the "Sulphite" effluent, however, should be returned to the post-sulphite washing stage. It is of high set point and already exhibits some discolouring caused presumably by "oversulphiting". Further sulphiting treatment can only cause deterioration in its quality.

DESIGN OF FULL SCALE UNITS

1. Throughput

The data provided from the pilot plant work is sufficient for the design of full scale units of any throughput.

Two alternative designs A and B have been worked out here, each capable of dealing with a throughput of 1,200 g.p.h. - under summer conditions - for an effluent exit temperature of 30°C. A throughput of this volume is sufficient to deal with either the "Acid" or the "Sulphite" effluent when three trinitration units are in operation on one leg, i.e. approximately 320 s. tons/week pure T.N.T. production - as shown below :-

Acid Effluent

Crude flow from 2 trinitration units = 3,200 lb./hr. (1)
(allowance made for stoppages)

Crude flow from 3 trinitration units = 4,800 lb./hr.

Volume at density 1.44 = 335 g.p.h.

Presulphite wash at a ratio of 3 : 1
water : T.N.T. by volume (3) = 335 x 3 = 1,005 g.p.h.

+ Extra water to deal with added recovered material, say 150 g.p.h.

Total = 1,200 g.p.h.

Sulphite Effluent

Volume of spent sulphite effluent = say 300 g.p.h.

Post sulphite wash, requiring a
ratio of $2\frac{1}{2}$: 1 by volume = 700 g.p.h.

Total = 1,000 g.p.h.

Using Carbonate and With Recovery of Sulphuric Acid

Should the suggestions outlined in Report P.181-3 (4) for sulphuric acid recovery and carbonate washing be put into operation, one crash cooler of the above throughput would be capable of dealing with the combined effluents from the carbonaters (approx. 150 g.p.h.) and the normal sulphite effluent (1,000 g.p.h.)

Cold Sulphiting

In the event of the introduction of cold sulphiting which is now under development, only the hot effluent will require crash cooling treatment, and a cooler of smaller throughput will be sufficient. In any case, the following detailed designs may be used as a basis for crash cooling units of any desired throughput.

2. Choice of Cooling Water Feed

The following table gives the relation between the cooling water flows and the cooling area requirement. The calculations were based upon the following assumptions :-

(a) Effluent flow = 1,200 g.p.h.

(b) Effluent Inlet temp. = 87°C.

(c) Effluent Outlet temp. = 30°C.

No temperature gradient in cooler - Uniform temp. of 30°C.

(d) Specific Heat of Effluent = 1 B.T.U./lb.

(e) Cooling Water inlet temp. = 17°C.

(f) Overall Coefficient of Heat Transfer = 150 B.T.H./Hr./sq.ft./°F.

Total Cooling Water Flow G.P.H.	Outlet Temp. of Cooling Water °C.	Log. Mean Temp. °C.	Area of Cooling Area sq.ft.
6,000	28.4	5.4	780
8,000	25.5	8.0	530
10,000 (Feed Chosen)	23.8	9.2	462
12,000	22.7	9.9	430
14,000	21.9	10.5	405

On this basis a cooling water feed of 10,000 G.P.H. was chosen for both designs.

3. Materials of Construction

(a) Sulphite Effluent

It is known that either mild steel or stainless steel is a suitable material of construction for this effluent . - The Sulphite Effluent labyrinths of the present recovery system are of mild steel construction. - Lead, however, is less suitable. The 5/16" thick lead lining of vessels used for a continuous sulphiting operation (80°C.) in the Purification House (P.24) disappeared completely in the course of 1 year's use.

The Overall Coefficient of Heat Transfer is similar for bothe mild steel and stainless steel coils, and the "icing" effects, under the varying conditions of the investigation, were also alike for the two materials.

The choice between a mild steel or stainless steel construction is, therefore, one of capital cost and maintenance costs, the stainless steel unit having the greater capital cost but probably the smaller maintenance cost.

(b) Acid Effluent

Here the choice is between lead and stainless steel and of the two materials stainless steel is considered the more suitable.

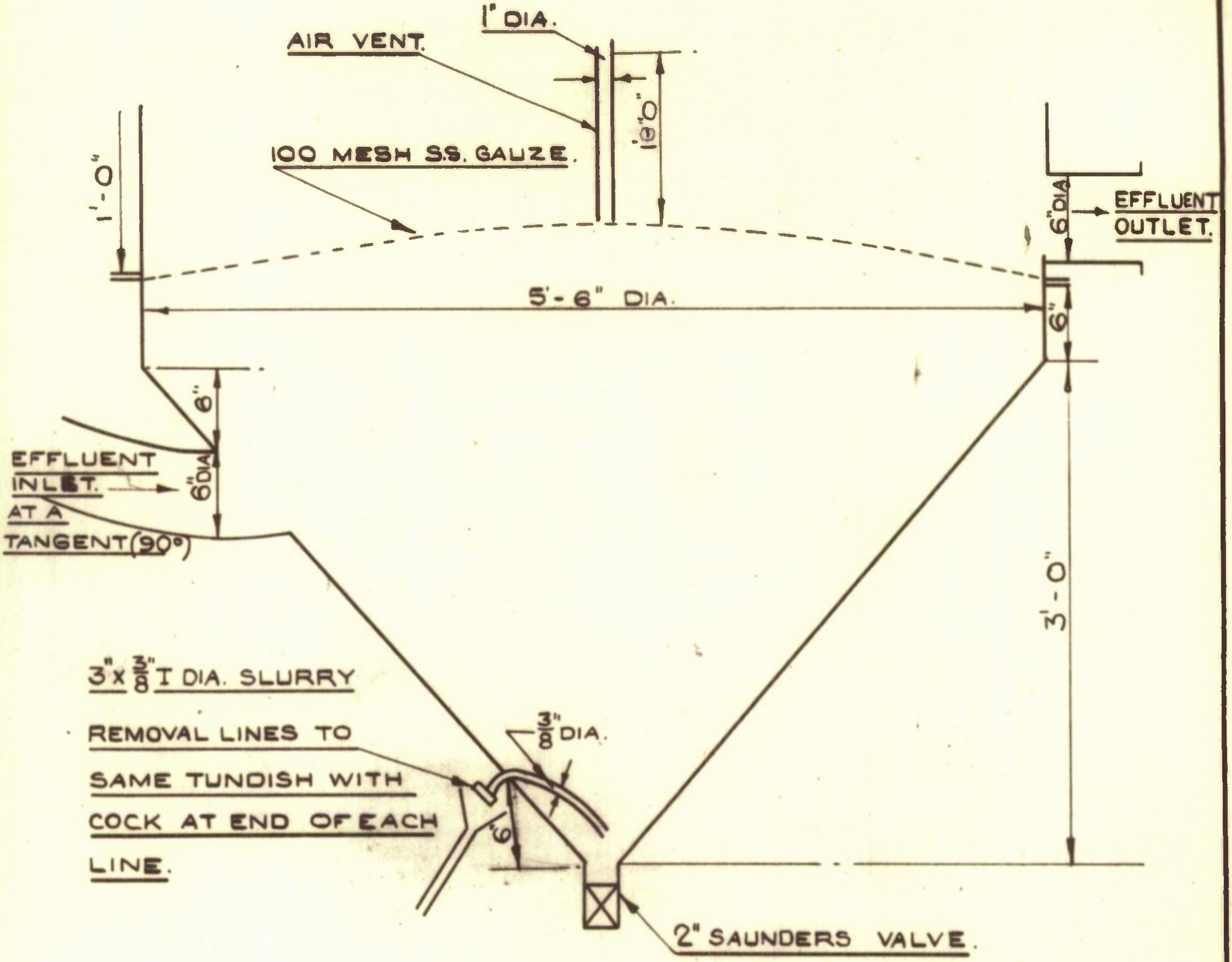
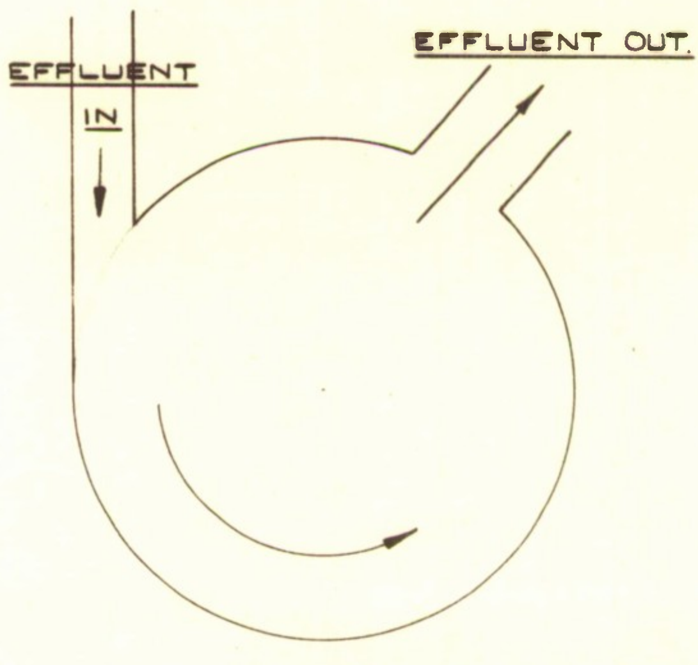


DIAGRAM OF FULL SCALE SLURRY SEPARATOR FOR USE WITH SINGLE UNIT CRASH COOLER.
DESIGN FOR 'A' COOLER.



PLAN.

DRG. No. C.P. 318

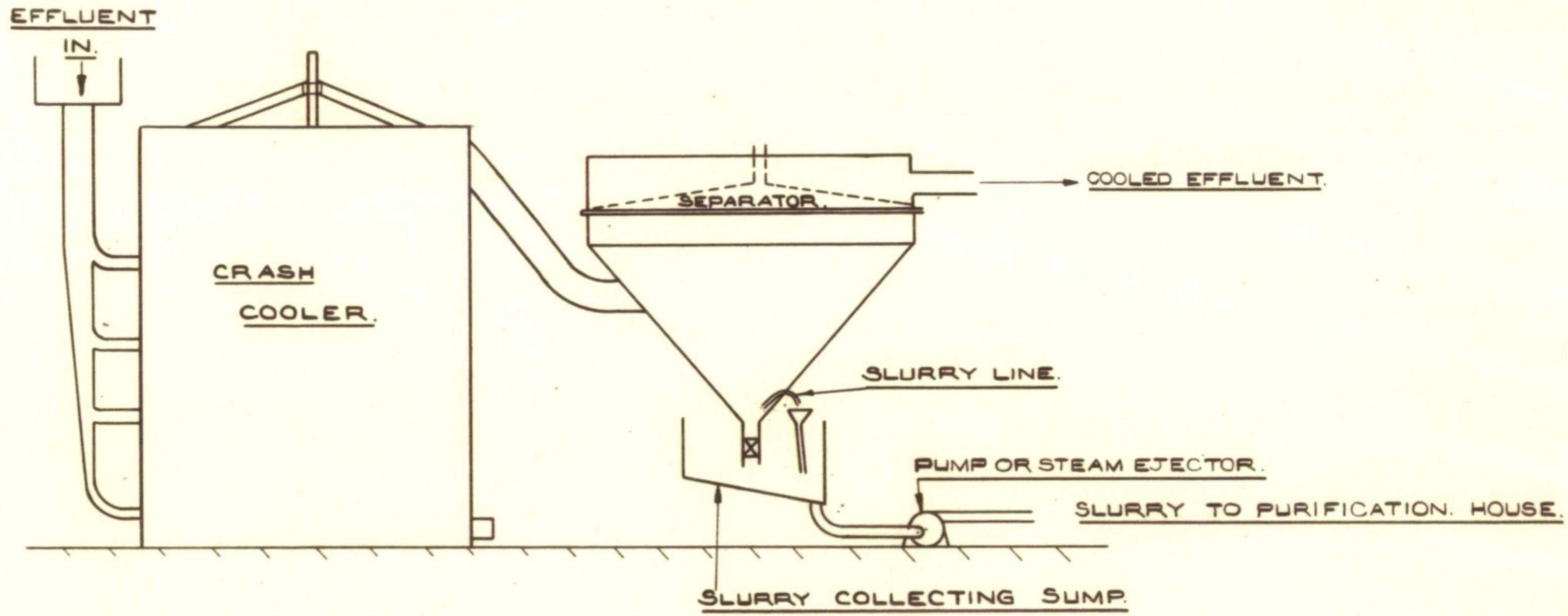


DIAGRAM OF SINGLE UNIT CRASH COOLING PLANT.

DRG. No. C.P. 315

4. Design A : With Single Crash Cooling Unit

This Unit has been designed to utilise a redundant mild steel, lead lined, batch washer (5' 6" i.d. x 7' Ht.) removed from the purification house (P.24) on the introduction of the continuous purification process. For use with a sulphite effluent the lead lining will be removed. The working liquid level of 5' 9" is too high for the present effluent ducts which are 4' 6" from floor level, so that for the implementation of this design the level of the ducts would have to be raised and/or the floor level lowered. Neither of these modifications should be difficult.

General Layout

The layout for Design "A" is shown diagrammatically in Drawing C.P.315.

In this design the "Crash Cooling" takes place in a single vessel, 5' 6" i.d. x 6' 6" ht. Entry of the hot effluent is at four points. This is designed to reduce local heating of the liquid in the cooler, with consequent decreased coil icing. The cooled (30°C.) effluent, containing particles of solid nitrobody, overflows near the top of the cooler into a large single separator of pilot plant design. The separated liquid portion, which will contain approximately 0.03% (1, 2) of T.N.T. in solution, may be disposed of to drain, or alternatively passed into the existing recovery pond system for further cooling to atmospheric temperature. The solid portion, which leaves the separator as a slurry may be pumped back to the purification plant, using a diaphragm or other safe type of pump. Alternatively a steam ejector could be used.

Separator Design

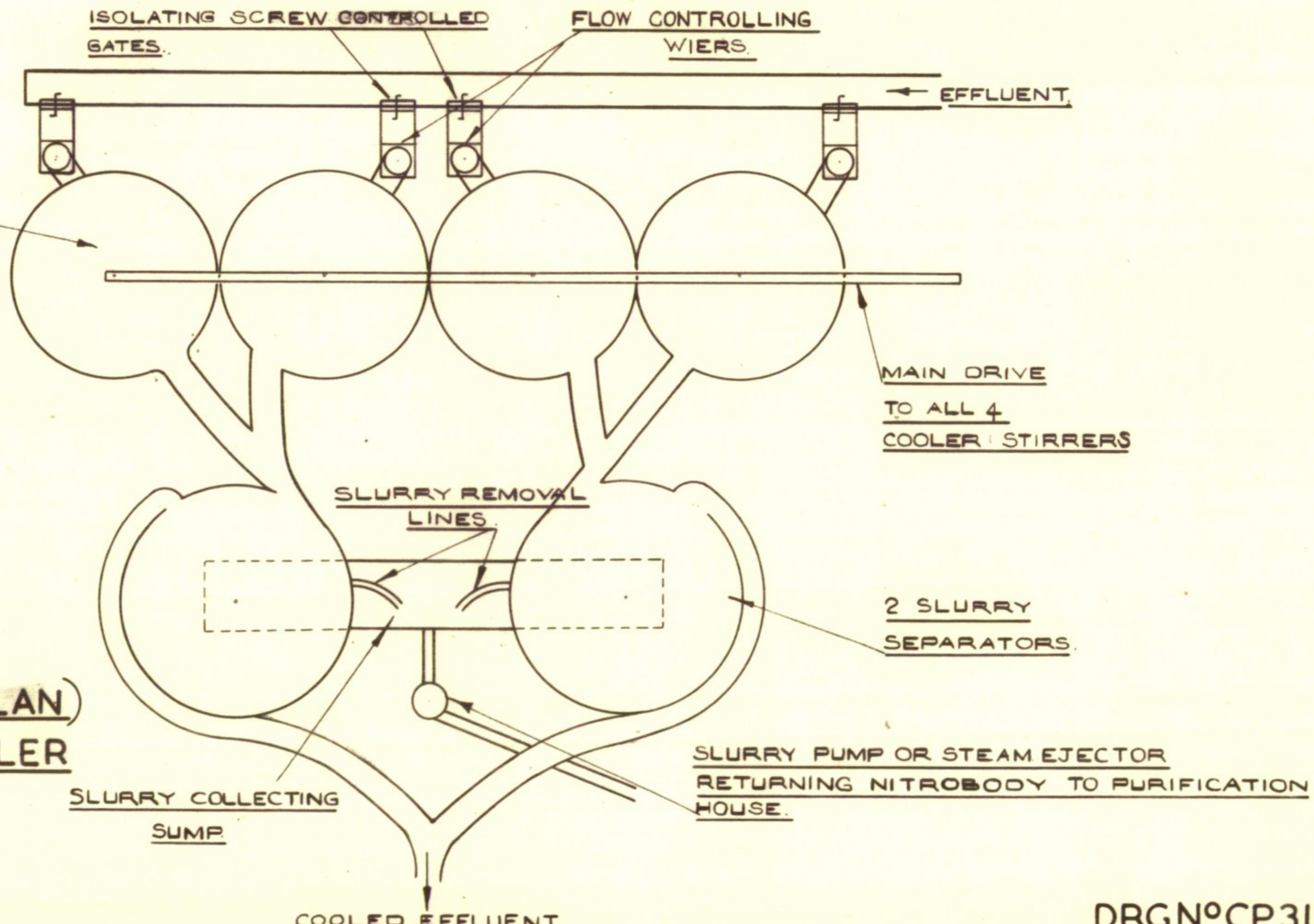
A design suitable for an effluent throughput of 1,200 g.p.h. is illustrated in Drawing C.P.318. The filter area for this design has been increased almost proportionally - i.e. eight times that of the pilot plant - to the increase in the effluent flows, whilst the working separator volume has been increased 14 times, by an increase in the liquid height from 2' to 3' 6". This height allows a 2' 3" clearance from the apex of the inverted cone to floor level which is sufficient for the drain valve and slurry pumping arrangement.

The effluent entry line has been retained at a tangent, an arrangement that proved so beneficial in the pilot plant design, but is has been positioned somewhat lower in the body of the separator as a further aid to separation. The effluent exit line has also been repositioned to a location 2/3 of the circumference - in the direction of the liquid rotation - from the entry line. This modification should enable full advantage to be obtained from the rotary movement engendered by the oblique entry of the effluent into the separator. With these improvements in the design, and the increased volume of the separator, the filter mesh may prove to be unnecessary as an aid to separation.

The $\frac{3}{8}$" slurry line has been retained, but the liquid head to the line has been increased from 2' to 3'. The line has also been shortened to reduce the tendency to blockage. From pilot plant experience, one such line should be sufficient for the removal of all the slurry but three lines, each with a cock, and emptying into a common tundish, have been provided in this first design, so that the slurry density can be varied as required. The 2" drain line and Saunders valve have also been retained. Both slurry lines and drain line empty into a common duct sloping downwards to the pump or steam ejector for continuous return of slurry to the purification plant.

Cooler Design

Details of the "step up" calculations from pilot plant design and dimensions to a full scale cooler for a throughput of 1,200 g.p.h. of effluent, together with drawings, are given in Appendix No.1.



LAYOUT DIAGRAM (PLAN) FOR 4 CRASH COOLER SYSTEM DESIGN 'A'.

DRG. No. C.P. 319

5. Design B : Four Cooling Vessels - Two Separators

General Layout

The layout of this unit is shown diagrammatically in plan form in Drawing C.P.319. In this design the crash cooling is carried out in four, single coil, cooling vessels (4' i.d. x 5' Ht. with a working liquid level of 4' 5") operated in parallel. - An arrangement for cooling vessels arranged in series is impracticable because of the rapid icing of the coil that occurs at temperatures above 30°C. - The effluent flow from the purification plant is divided into four equal flows by means of weirs. Screw controlled gates have also been provided for the isolation of any of the coolers at times when the full cooling capacity is not required, or for maintenance.

The four coolers have been arranged in line to simplify the stirring arrangement, each gate type paddle stirrer being driven from a main belt-driven shaft by means of bevelled gearing, but alternatively individual stirring units may be employed.

Cylindrical cooling vessels are shown in the diagrams but one large rectangular tank divided into four sections - or alternatively two rectangular tanks divided into two sections - could be employed with some economy in space and possibly construction cost.

The cooled effluent containing suspended nitrobody from each pair of coolers is shown directed into a single solid/liquid separator of pilot plant design, making two separators in all, the recovered nitrobody slurry from each flowing into a single duct sloping to a pump or steam ejector for continuous return to the purification plant.

Separator Design

Separators of similar design but of smaller size to that detailed for Design A would be appropriate to this design. Separators of filter diameter 4' 0" and with a 2' 6" working head of liquid should be adequate for a throughput of 600 g.p.h.

Cooler Design

Details of the "step up" calculations from pilot plant design and dimensions, together with drawings, are given in Appendix No.2.

In this design, the gate-paddle scrubs one side of the coil only. An improved version where both sides of the coil are scrubbed could easily be arranged along the lines indicated in Design A, with improved operation but occupying a somewhat larger floor space.

6. Advantages and Disadvantages of Designs A and B.

Design A.

Advantages

1. The design utilizes a redundant washer otherwise only suitable for scrap.

2. The design is extremely compact, with considerable economy in space and materials.

3. Only one stirrer mechanism is required.

4. The effluent is not split into several coolers so that there is no complication of maintaining equal feeds to the coolers.

Disadvantages

1. Parts of the unit cannot be shut down for maintenance purposes.

2. The cooler design is rather complicated and the larger size of the cooler makes the maintenance handling more difficult, e.g. coil maintenance.

Design B.

Advantages

1. Parts of the unit can be shut down independently for maintenance etc.

2. The cooler design is very simple, parts are easy to handle for maintenance purposes.

Disadvantages

1. The design is not as compact as A.

2. Four stirrer mechanisms are required.

3. The effluent feed has to be split and maintained as 4 equal flows, one to each cooler.

CONCLUSIONS

1. A "Crash Cooling" Unit of the design indicated here, is practicable for the treatment of the "Acid" or "Sulphite" Effluents from the T.N.T. purification plant, provided that the cooler effluent exit temperature does not greatly exceed 30°C.

2. At higher effluent exit temperatures severe icing of the coil takes place, the rate at which icing forms increasing with increasing temperature. A maximum outlet temperature of 30°C. is indicated for design purposes.

3. The Overall Coefficients of heat transfer and the rate of icing under similar conditions are roughly comparable for coils fabricated from lead, stainless steel or mild steel.

4. The cooling coils can be rapidly de-iced by passing steam through the cooling coils, without the necessity of stopping the effluent flow.

5. The use of a gate-paddle stirrer and baffles - with a small clearance between the paddle and the coil - provides effective mixing, gives a high value for the overall Coefficient of Heat Transfer, and is beneficial in reducing the amount of icing on the inner side of the coil.

6. A continuous solid/liquid separator of the design developed here, is effective in maintaining a final effluent free from entrained nitrobody whilst providing a continuous delivery of recovered nitrobody in a convenient slurry form.

7. The circulation of the liquid in the separator, promoted by the entry of the effluent at a tangent, improves the efficiency of the separation.

APPENDIX NO. 1

DESIGN A.

Design for Full Scale Crash Cooler for P.24 Effluent utilising spare P.24 Washer

Assumptions

1. Water flow of 10,000 g.p.h. available for cooling purposes at 17°C.

2. Pipes used for cooling coils 2" internal diameter, $2\frac{1}{8}$" external diameter.

3. Effluent flow of 1,200 g.p.h. at 87°C. to be cooled to 30°C.

4. Overall heat transfer coefficient found by experiment to be taken as 150 B.T.U./hr./sq. ft./°F. This is based on outside area of pipe and on a pilot plant flow of 1,200 g.p.h. of cooling water with mean temperature 11°C.

5. Cooler to be a vertical cylindrical tank of 5' 6" internal diameter containing 3 cooling coils of mean diameters 4' 10", 3' 8" and 2' 10". Cooling water is passed through the coils in parallel.

A. Total Heat removed from Effluent

The gravity and specific heat of effluent are taken as for water

$$\therefore \text{Heat removed/hr.} = 1,200 \times 10 \times (87 - 30)$$

$$= 6.38 \times 10^5 \text{ C.H.U./hr.}$$

B. Cooling water outlet temperature

Let t be cooling water outlet temperature from all coils. Then by heat balance

$$10,000 \times 10 \times (t - 17) = 1,200 \times 10\,(87 - 30)$$

$$t - 17 = 6.8$$

$$t = 23.8^\circ\text{C.} = \text{cooling water outlet temp.}$$

C. Log. Mean Temperature Difference for all coils

$$\Delta t = \frac{(30 - 17) - (30 - 23.8)}{\text{Log}_e \dfrac{(30 - 17)}{(30 - 23.8)}}$$

$$= \frac{6.8}{\text{Log}_e 13/6.2}$$

$$= 9.2^\circ\text{C.} = \text{Log. Mean Temp. Difference}$$

D. Estimation of Cooling Water Rates to Each Coil

It is desirable from a design point of view to have the same number of turns per coil.

Now the heat transferred per coil must be proportional to the water flow since an equal temperature rise in each coils is assumed. Therefore,

assuming approximately the same overall coefficients of heat transfer for each coil the ratio of the water flows is the ratio of heat transfer surfaces or the ratio of the coil circumferences.

$\therefore$ Ratio of flows = inner coil : middle coil : outer coil

= π (2'10") : π (3'8") : π (4'10")

= 34 : 44 : 58

$\therefore$ Water to inner coil = 2,500 g.p.h.

" " middle " = 3,250 g.p.h.

" " outer " = 4,250 g.p.h.

E. Calculation of Overall Heat Transfer Coefficients

Calculation of water film coefficient in pilot plant coil :-

Use L $$= \frac{(5.6 + .058t)(G^1)^{0.8}}{(D^1)^{0.2}} \quad (5)$$

This is actually only applicable to straight pipes, the coefficients in coils being about 20% higher. To obtain this coil coefficient the straight pipe coefficient should be multiplied by $(1 + 3.5 \frac{Di}{Dc}) = (6)$

where Di = internal diameter of pipe

Dc = mean diameter of coil

Let L^1 be coefficient for straight pipe, L for coil

t = mean cooling water temperature = 11°C. = 52°F.

D^1 = internal pipe diameter = 1.1875"
(cross-section 1.108 sq. in.)

G^1 = mass flow rate = $\frac{12,000}{3,600} \times \frac{144}{1.108}$ = 434 lbs./sec./sq. ft.

$$\therefore L^1 = \frac{(5.6 + 3.02)(434)^{0.8}}{1.1875)^{0.2}}$$

$$= \frac{8.62 \times 128.8}{1.035}$$

= 1,072 B.T.U./hr./sq. ft./°F.

Now internal diameter of pipe = 1.1875" and mean diameter of coil = 14"

$$\therefore L = 1,072 \left(1 + 3.5 \times \frac{1.1875}{14}\right)$$

= 1,072 x 1.297

= 1,390 B.T.U./hr./sq. ft./°F. for pilot plant

F. Calculation of water film coefficients for design :-

Let L_i, L_m, L_o be film coefficients for inner, middle and outer coils respectively.

For Inner Coil :-

$$t = 20.4^{\circ}C. = 68.7^{\circ}F.$$

$$D^1 = 2.0'' \text{ (Cross-section area } = 3.1417 \text{ sq. in.)}$$

$$G^1 = \frac{25,000}{3,600} \times \frac{144}{3.1417} = 318 \text{ lbs./sec./sq. ft.}$$

$$\therefore L_i^1 = \frac{(5.6 + .058 \times 68.7)\ (318)^{0.8}}{(2.0)^{0.2}}$$

$$= \frac{9.60 \times 100}{1.1495}$$

$$= 837 \text{ B.T.U./hr./sq. ft./}^{\circ}\text{F.}$$

$$\therefore L_i = 837\ (1 + 3.5 \times \frac{2}{34})$$

$$= 837\ (1.206)$$

$$= 1,010 \text{ B.T.U./hr./sq. ft./}^{\circ}\text{F. for inner coil}$$

For Middle Coil :-

t and D^1 are the same

$$G^1 = \frac{3,250}{2,500} \times 318 = 414 \text{ lbs./sec./sq. ft.}$$

$$L_m^1 = \frac{9.60 \times (414)^{0.8}}{1.1495}$$

$$= 1,060 \text{ B.T.U./hr./sq. ft./}^{\circ}\text{F.}$$

$$\therefore L_m = 1,060\ (1 + 3.5 \times \frac{2}{44})$$

$$L_m = 1,060 \times 1.16$$

$$= 1,230 \text{ B.T.U./hr./sq. ft./}^{\circ}\text{F. for middle coil}$$

For Outer Coil :-

t and D^1 are the same

$$G^1 = \frac{4,250}{2,500} \times 318 = 541 \text{ lbs./sec./sq.ft.}$$

$$\therefore L_o^1 = \frac{9.60 \times (541)^{0.8}}{1.1495}$$

$$= 1,278 \text{ B.T.U./hr./sq. ft./}^{\circ}\text{F.}$$

$$L_o = 1,278\ (1 + 3.5 \times \frac{2}{58})$$

$$= 1,278 \times 1.121$$

$$= 1,433 \text{ B.T.U./hr./sq. ft./}^{\circ}\text{F. for outer coil}$$

To find U_i, U_m, and U_o overall coefficients for inner, middle and outer coils, let S be scale coefficient and neglect effect of pipe walls.

For Pilot Plant $\frac{1}{1390} + \frac{1}{S} = \frac{1}{150}$

For Inner Coil $\frac{1}{1010} + \frac{1}{S} = \frac{1}{U_i}$

For Middle Coil $\frac{1}{1230} + \frac{1}{S} = \frac{1}{U_m}$

For Outer Coil $\frac{1}{1433} + \frac{1}{S} = \frac{1}{U_o}$

$$\therefore \frac{1000}{U_i} = \frac{1000}{1010} + \frac{1000}{150} - \frac{1000}{1390}$$

$$= 0.99 + 6.67 - 0.72$$

$$= 6.94$$

$\therefore U_i$ = <u>144 B.T.U./hr./sq. ft./^oF. for inner coil</u>

$$\therefore \frac{1000}{U_m} = \frac{1000}{1230} + \frac{1000}{150} - \frac{1000}{1390}$$

$$= 0.81 + 6.67 - 0.72$$

$$= 6.76$$

$\therefore U_m$ = <u>148 B.T.U./hr./sq. ft./^oF. for middle coil</u>

$$\therefore \frac{1000}{U_o} = \frac{1000}{1433} + \frac{1000}{150} - \frac{1000}{1390}$$

$$= 0.70 + 6.67 - 0.72$$

$$= 6.65$$

$\therefore U_o$ = <u>150 B.T.U./hr./sq. ft./^oF. for outer coil</u>

G. <u>Area of Heat Transfer Surface Required/Coil</u>

Since rise in cooling water temperature in both coils is the same (assumed) the heat removed is split in the ratio of the water flows.

<u>For Inner Coil</u> :-

Use Q $= U A \Delta t$

where Q = heat transferred/hr. $= \frac{2,500}{10,000} = 6.83 \times 10^5$

$= 1.76 \times 10^5$ C.H.U./hr.

U_i = 144 C.H.U./hr./sq. ft./^oC.

Δt = 9.2^oC. (Log. mean temperature difference)

$\therefore A = \frac{Q}{U_i \Delta t} = \frac{1.76 \times 10^5}{144 \times 9.2}$ = <u>133 sq. ft. of inner coil</u>

For Middle Coil :-

$$Q = \frac{3,250}{10,000} \times 6.83 \times 10^5 = 2.22 \times 10^5 \text{ C.H.U./hr.}$$

$$U_m = 148 \text{ C.H.U./hr./sq. ft./}^\circ\text{C.}$$

$$\Delta t = 9.2^\circ\text{C.}$$

$$\therefore A = \frac{2.22 \times 10^5}{148 \times 9.2} = \underline{163 \text{ sq. ft. of middle coil}}$$

For Outer Coil :-

$$Q \quad Q = \frac{4,250}{10,000} \times 6.83 \times 10^5 = 2.85 \times 10^5 \text{ C.H.U./hr.}$$

$$U_c = 150 \text{ C.H.U./hr./sq. ft./}^\circ\text{C.}$$

$$\Delta t = 9.2^\circ\text{C.}$$

$$\therefore A = \frac{2.85 \times 10^5}{150 \times 9.2} = \underline{207 \text{ sq. ft. of outer coil}}$$

H. Length of Coil

$$\text{Inner} = \frac{133}{\pi \times \frac{2.125}{12}} = 239 \text{ ft.}$$

$$\text{Middle} = \frac{163}{\pi \times \frac{2.125}{12}} = 300 \text{ ft.}$$

$$\text{Outer} = \frac{207}{\pi \times \frac{2.125}{12}} = 381 \text{ ft.}$$

I. Number of Turns/Coil

Let there be n turns/coil

Inner Coil :-

$$239 = \pi \times \frac{34}{12} \times n$$

$$\therefore n = \frac{239 \times 12}{\pi \times 34} = 26.8$$

Middle Coil :-

$$300 = \pi \times \frac{44}{12} \times n$$

$$\therefore n = \frac{300 \times 12}{\pi \times 44} = 26.0$$

Outer Coil :-

$$381 = \pi \times \frac{58}{12} \times n$$

$$\therefore n = \frac{381 \times 12}{\pi \times 58} = 25.1$$

Let there be 26 turns/coil

J. Immersed Depth of Coil

Allowing $\frac{1}{2}$" space between turns of coil the immersed depth of coil

$$= 26 \times (2\tfrac{1}{8} + \tfrac{1}{2})$$

$$= 68\tfrac{1}{4}"$$

$$= \underline{5' \; 9" \text{ immersed coil depth}}$$

Calculation of Pressure Drop

Since the outer coils are the largest and have the largest water flow they will have the maximum pressure drop.

Calculation of Reynolds No. :-

Viscosity K = .000672 x 1.01 lbs. ft./sec. (20.4°C.)

Diameter of pipe D = 2.0/12 ft.

Mass flow rate G = 541 lbs./sec./sq. ft. (See Section E)

$$\therefore Re = \frac{(DG)}{K} = \frac{2.0}{12} \times \frac{541}{.000672 \times 1.01} = 1.33 \times 10^5$$

Calculation of Pressure Drop

Assuming pipe to be straight, friction factor = 0.0055 (5)

Now $F = \frac{4 \, f \, N \, V^2}{2gD}$ where

F = pressure drop ft. lb./lb.

f = 0.0055 = friction factor

N = 381 ft. = length of pipe

$V = \frac{G}{62.4} = \frac{541}{62.4} = 8.67$ ft./sec. = velocity of flow

g = 32.2 ft./sec^2 = acceleration of gravity

D = 2.0/12 ft. = internal diameter of pipe

$$\therefore F = \frac{4 \times .0055 \times 381 \times 8.67^2}{2 \times 32.2 \times 2.0/12}$$

$$= 58.6 \text{ ft. lb./lb.} = \frac{58.6 \times 62.4}{144} = 24.4 \text{ lbs./sq. in.}$$

No allowance has been made for curvature or head through the vessel. A supply of water at 30 lb./sq. in. would thus probably be required.

K. Size of Paddles and Speed of Rotation

Let there be $\frac{3}{4}$" clearance between paddle and coil. The paddles are of the gate type with a central several bladed paddle and a number of outer rotating "scrubbers" between the middle and outer coil. This gives one side of each coil under the scrubbing action of a paddle as in the pilot plant.

∴ Let inner paddle have diameter 2' $6\frac{1}{2}$"

Let scrubbers have inner diameter of 3' $11\frac{1}{2}$" and outer diameter of 4' $6\frac{1}{2}$"

Now on the pilot plant the single flat paddle (2 blades) rotates at 123 r.p.m. and has diameter of 9"

Let x be speed of rotation of paddles. Then for end of paddle to pass coil at same velocity as in pilot plant (i.e. to give same scrubbing effect).

$$123 \times \pi \times 9 = X \times \pi \times 30.5$$

$$X \simeq 36 \text{ r.p.m. for inner paddle}$$

$$123 \times \pi \times 9 = X \times \pi \times 47.5$$

$$X \simeq 23 \text{ r.p.m. for inner scrubber edge}$$

$$123 \times \pi \times 9 = X \times \pi \times 54.5 \text{ for outer scrubber edge}$$

$$X \simeq 20$$

To simplify the design, one speed of 30 - 35 r.p.m. should be suitable.

Now on the pilot plant the end of the blade passes any point on the coil, 123 x 2 = 246 times/min.

For the same effect as on the pilot plant, if there are y blades on design plant

$$246 = 30\,y$$

$$\therefore y = 8.2$$

Let the paddles have 8 single or 4 double blades

SUMMARY OF DIMENSIONS AND MATERIALS FOR DESIGN "A"

1. Crash Cooler

Cooling Vessel	-	5' 6" I.D. x 6' 6" (Liquid level 5' 9")
Coils	-	Pipe of 2" I.D. and $2\frac{1}{8}$" O.D.
	-	26 turns per coil ($\frac{1}{2}$" between turns)
	-	Mean diameters of 4' 10", 3' 8" and 2' 10"
Paddles	-	8 blades - 2' 6.5" diameter
Scrubbers	-	8 blades - 3' 11.5" inner diameter 4' 6.5" outer diameter
Clearance	-	coil/paddle or scrubber $\frac{1}{4}$"
Baffles	-	6 outer, 2.75" wide
	-	6 inner, 2.5" wide

2. Separator

Diameter of cone base 5' 6"

Height from base of cone to apex 3' 6"

Slurry removal lines $\frac{3}{8}$" I.D. - 3 off

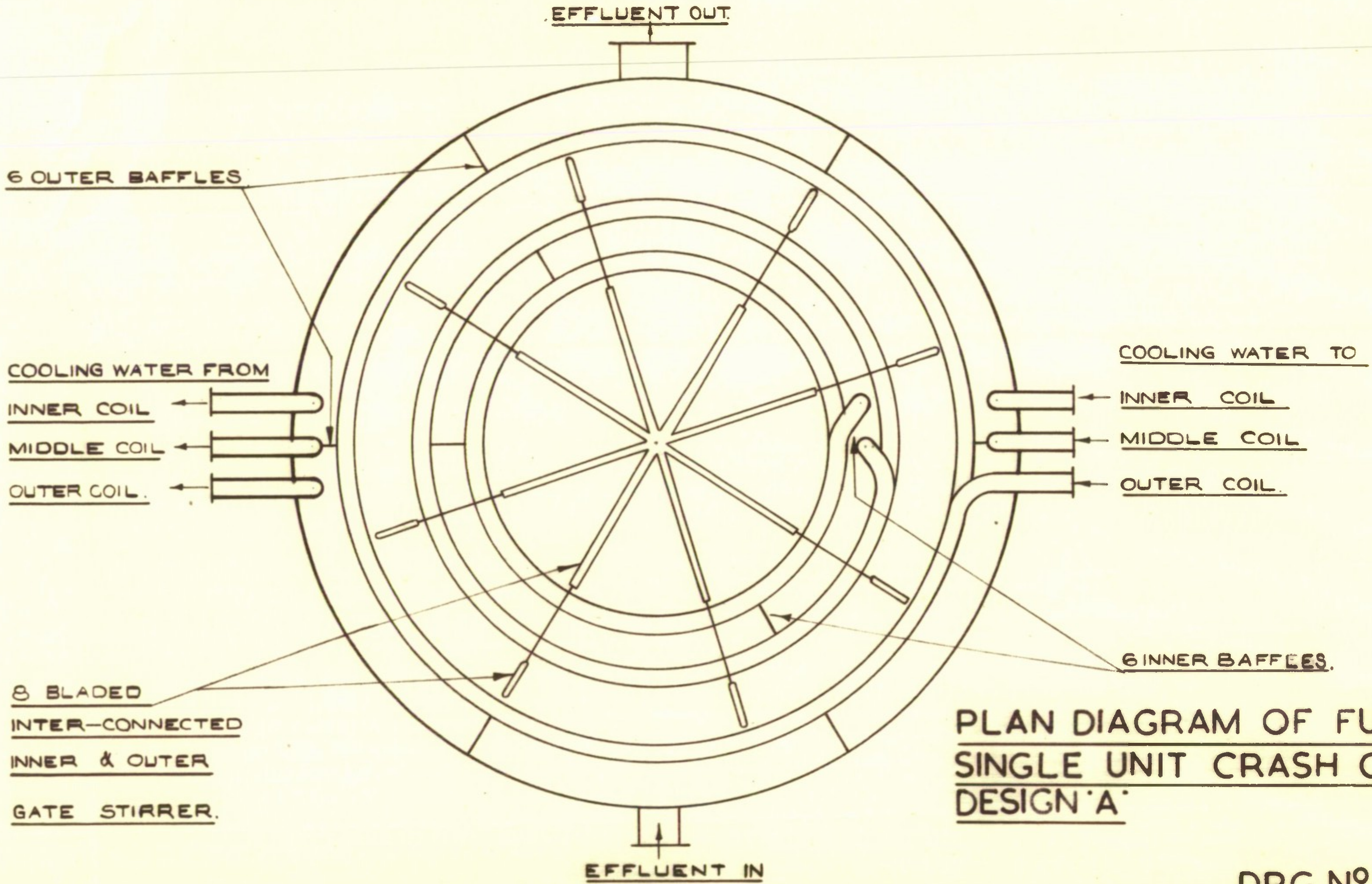
Drain line 2" I.D. - sealed by Saunders valve

3. Materials of Construction

For "Sulphite" effluent, stainless or mild steel

For "Acid" effluent, stainless steel (Cooling vessel may be lead lined)

For Filtering 100 mesh, stainless steel for both effluents



PLAN DIAGRAM OF FULL SCALE SINGLE UNIT CRASH COOLER, DESIGN 'A'

DRG. Nº C.P. 317.

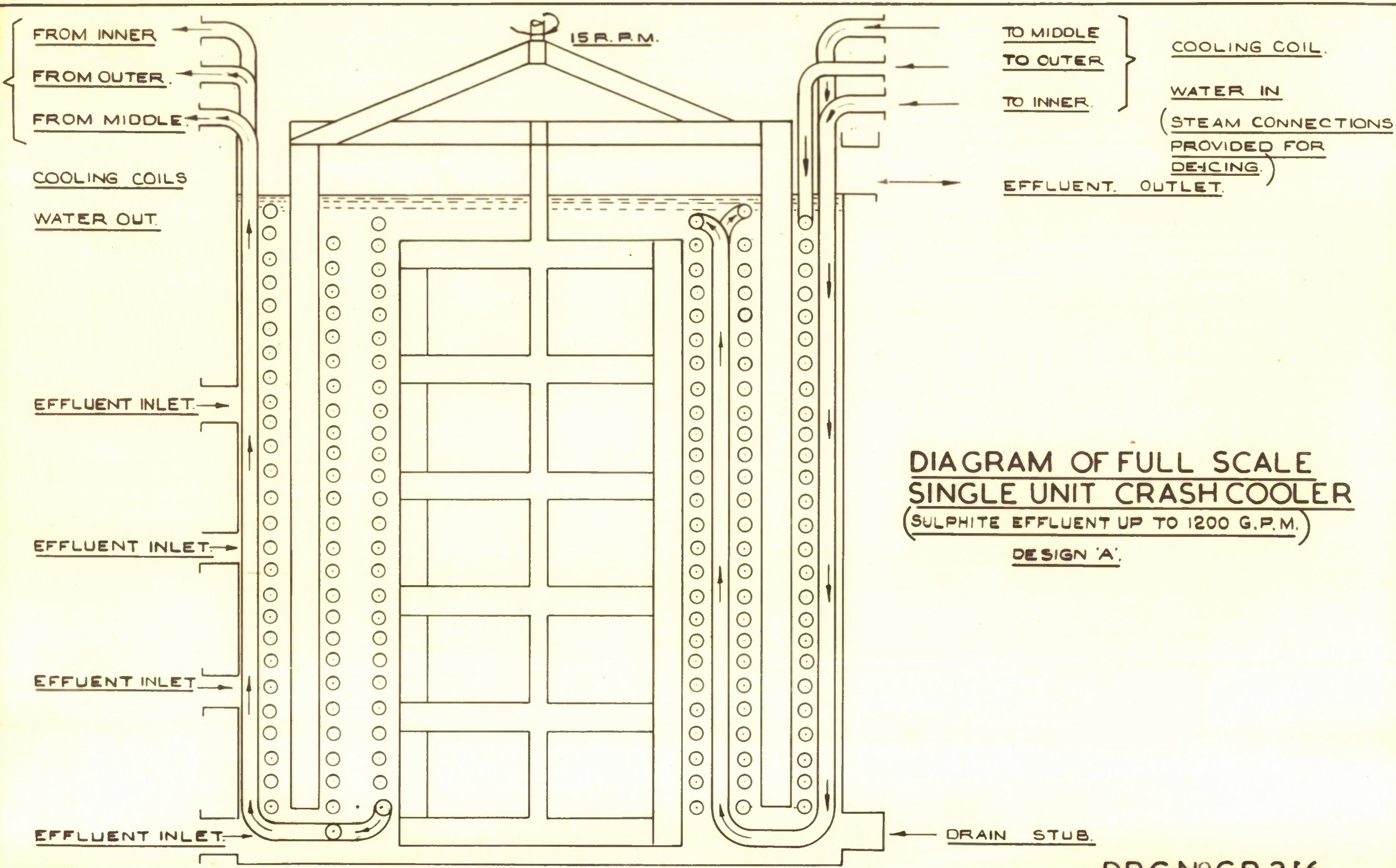


DIAGRAM OF FULL SCALE SINGLE UNIT CRASH COOLER

(SULPHITE EFFLUENT UP TO 1200 G.P.M.)

DESIGN 'A'.

DRG No. C.P. 316.

APPENDIX NO. 2

DESIGN B.

Alternative Design for Crash Cooling using four similar coolers in parallel with equally split flows

Assumptions

1. Water flow of 10,000 g.p.h. available for cooling purposes at 17°C.

2. Pipes used for cooling coils 2" internal diameter, $2\frac{1}{8}$" external diameter.

3. Effluent flow of 1,200 g.p.h. at 87°C. to be cooled to 30°C.

4. Overall heat transfer coefficient found by experiment to be taken as 150 B.T.U./hr./sq. ft./°F. This is based on outside area of pipe and on a pilot plant flow of 1,200 g.p.h. of cooling water with mean temperature 11°C.

5. Each cooler to contain one coil of piping (internal diameter 2", external $2\frac{1}{8}$) and mean coil diameter 3' 6". Cooler to have internal diameter 4 ft.

A. Heat Removed/hr. per cooler

$= \frac{1}{4} \times 6.38 \times 10^5 = 1.6 \times 10^5$ C.H.U./hr.

B. Cooling Water Outlet Temperature

Since again 10,000 g.p.h. of water used and split evenly, 2,500 g.p.h. to each cooler, exit temperature of water is again 23.8°C.

C. Log. Mean Temperature Difference

Again 9.2°C.

D. Calculation of Overall Heat Transfer Coefficient

The pilot plant water film coefficient remains as 1,390 B.T.U./hr./sq. ft./°F.

For the design, since 2,500 g.p.h. of water is being used

$L^1 = L_i{}^1 = 837$ B.T.U./hr./sq. ft./°F. - for straight pipe

For coil $L = 837 \left(1 + 3.5 \times \frac{2}{42}\right)$

$= 837\ (1.167)$

$= 975$ B.T.U./hr./sq. ft./°F.

If U is the overall coefficient, as before,

For pilot plant $\frac{1}{1390} + \frac{1}{S} = \frac{1}{150}$

" design " $\frac{1}{975} + \frac{1}{S} = \frac{1}{U}$

$$\therefore \frac{1000}{U} = \frac{1000}{975} + \frac{1000}{150} - \frac{1000}{1390}$$

$$= 1.03 + 6.67 - 0.72$$

$$= 6.98$$

$\therefore$ U = 143 B.T.U./hr./sq. ft./°F. = overall coefficient

E. Area of Heat Transfer Surface Required/Cooler

Use $Q = U A \Delta t$

where Q = heat transferred/hr. = 1.6×10^5 C.H.U./hr.

U = overall heat transfer coefficient

= 143 C.H.U./hr./sq. ft./^oC.

Δt = 9.2^oC.

$\therefore A = \dfrac{1.6 \times 10^5}{9.2 \times 143} = 121.6$ sq. ft.

F. Length of Coiled Pipe/Cooler

$= \dfrac{121.6}{\pi \times \frac{2.125}{12}} = 218$ ft. of pipe

G. Number of Turns/Coil

Let there be n turns/coil with $\frac{1}{2}$" between turns

$218 = \pi \times \dfrac{42}{12} \times n$

$n = \dfrac{218 \times 12}{\pi \times 42} = 20$ turns

H. Immersed depth of Coil

$= 20 \, (2\frac{1}{8} + \frac{1}{2})$

$= 52\frac{1}{2}" = 4' \, 4\frac{1}{2}"$

Calculation of Pressure Drop/Cooler

Calculation of Reynolds No. :-

Viscosity K = $1.01 \times .000672$ lbs. ft./sec. (20.4^oC.)

Diameter D = 2.0/12 ft.

Mean flow rate G = 318 lb./sec./sq. ft. (See Section E Appendix I)

$Re = \left(\dfrac{DG}{K}\right) = 2.0 \times \dfrac{318}{1.01 \times .000672}$

$= 7.8 \times 10^4$

Calculation of Pressure Drop :-

Assuming pipe to be straight, friction factor

$f = 0.006$ (6)

Now $F = \dfrac{4 \, f \, N \, V^2}{2 \, g \, D}$ where

F = pressure drop ft. lb./lb.

f = friction factor = 0.006

N = length of pipe = 218 ft.

V = velocity of flow = $\frac{G}{62.4}$ = 5.1 ft./sec.

g = acceleration of gravity = 32.2 ft./sec.^{2}

D = diameter of pipe = 2.0/12 ft.

$$\therefore F = \frac{4 \times .006 \times 218 \times 5.1^2}{2 \times 32.2 \times 2/12}$$

$$= 12.7 \text{ ft. lb./lb.}$$

$$= \frac{12.7 \times 62.4}{144} = 5.5 \text{ lb./sq. in.}$$

Since coolers would be in parallel and flow split evenly maximum pressure drop required calculated as straight pipe would be 5.5 lb./sq. in. Allowing for curvature and head through the cooler a supply at 17°C. of 10,000 g.p.h. at 10 lb./sq. in. would be sufficient.

I. Size of Paddles and Speed of Revolution

Let there be $\frac{3}{4}$" clearance between paddle and coil. Then paddle diameter = 3' $2\frac{1}{2}$"

Then if X is speed of rotation, as in part I

$$123 \times \pi \times 9 = X \times \pi \times 38$$

$$\therefore X \quad 29 \text{ r.p.m.}$$

$\therefore$ Paddle rotates at 30 r.p.m. to ensure good cleaning effect.

Again as before if there are y blades

$$246 = 30y$$

$$\therefore y = 8.2$$

$\therefore$ Paddle has 8 single or 4 double blades to simplify design.

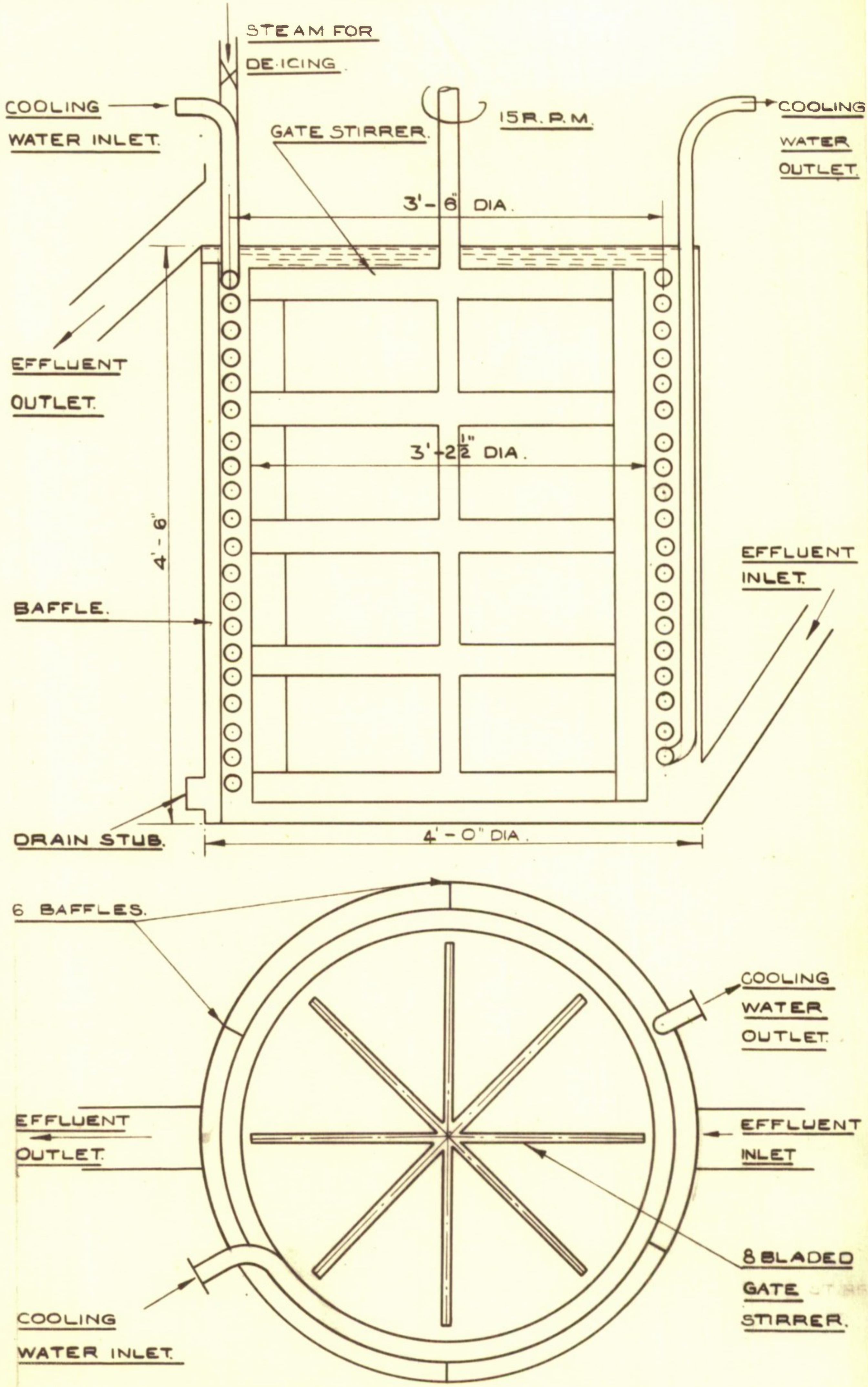


DIAGRAM OF INDIVIDUAL CRASH COOLER
FOR USE IN 4 COOLER STYSTEM.
DESIGN 'B'

DRG.Nº C.P. 320.

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Record Summary:

Title: Treatment of TNT effluents (crash cooling)
Covering dates 1955
Availability Open Document, Open Description, Normal Closure before FOI Act: 30 years
Former reference (Department) Report No P.181-4
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